# Research Priorities for the Management of the Western Toad, *Bufo boreas*, in British Columbia

by
T. M. Davis

Wildlife Working Report No. WR-106

**March 2002**

*British Columbia, Canada's most westerly province, has a bounty of biological diversity. British Columbia's snowclad peaks, rain-drenched forests, arid grasslands, all sizes of rivers, lakes, and wetlands, and a long and rugged coast provide habitats for more species of living organisms than are found anywhere else in Canada. However, this very diversity means that there is much to be discovered about these organisms — their distribution, abundance, habitat requirements, and interrelationships with their environment. Increasing our knowledge of this biodiversity will help us with the complex task of sustainably managing our land and waters.*

*In 1992, the Provincial Government initiated a co-operative biodiversity research program with funding from the Corporate Resource Inventory Initiative, the British Columbia Ministries of Forests (Research Branch), Environment, Lands, and Parks (Wildlife and Habitat Protection Branches), and Tourism and Culture (Royal B.C. Museum); and the Forest Resource Development Agreement (FRDA II).*

*In 1995, the Ministry of Forests Research Branch and the Ministry of Environment, Lands and Parks developed a biodiversity research and extension strategy, with the assistance of the provincial research community. This strategy was presented to Forest Renewal BC (FRBC), who provided funding for a program beginning in 1995. The goal of the extension component of this program is to extend information to scientists, resource managers, and the public through biodiversity publications. These publications are intended to increase awareness and understanding of biodiversity, promote the concepts and importance of conserving biodiversity, and communicate provincial government initiatives related to biodiversity. We hope that they will be used as tools for the conservation of British Columbia's rich, living legacy.*

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B.C. Ministry of Water, Land and Air Protection
Biodiversity Branch
Victoria BC

Wildlife Working Report No. WR-106
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**Working Report**

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## FOREWORD

In cases where a Wildlife Working Report or Bulletin is also a species' status report, it may contain a status recommended for the species by the author(s). This recommended status designation is the opinion of the author(s) and may not necessarily reflect that of the Biodiversity Branch. The Biodiversity Branch, in consultation with experts, will make official status designation and the data contained in the status report will be considered during the evaluation process.

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## SUMMARY

Over the past several decades, amphibian populations have undergone population declines, range reductions, or extinctions as the result of human population growth and activities. The most important factor has been habitat loss or degradation, but the introduction of exotic predators and pathogens, harvesting by humans, road mortality, and habitat fragmentation also have contributed to amphibian declines. Although most losses have occurred as the direct consequence of human activities, some have occurred in relatively pristine habitats. The cause(s) of losses in undisturbed habitats are often difficult to identify, but acid rain, pollution, increased ultraviolet flux, and the introduction of exotic pathogens have been suggested.

Declines in the number and size of amphibian populations in North American temperate-zone forests are thought to be primarily, but not exclusively, the result of logging, which typically leads to fragmentation, modification, or loss of habitat. Other human activities, including land conversion, urbanization, livestock grazing, hydroelectic projects, recreation, and the introduction of exotic species, have also resulted in the loss and degradation of critical habitat. Roads are of particular importance because they subdivide continuous habitat, disrupt metapopulation dynamics, and are the source of considerable direct mortality by motor vehicles.

The Western Toad (*Bufo boreas*) occurs from southern Alaska to Baja California and as far east as Colorado and Utah, and is found throughout British Columbia. Because of declines and local extinctions over much of its range in the United States, *B. boreas* is red-listed by The World Conservation Union (IUCN). Disease, habitat modification, susceptibility to UV radiation, acid precipitation, and predation have been suggested as possible causes for its decline. Its current distribution, abundance, and population trends in British Columbia are largely unstudied, but there is some evidence suggesting declines on southern Vancouver Island.

The objective of this report is to outline research priorities for the management of the Western Toad in British Columbia. Because *B. boreas* has suffered dramatic population declines over much of the southern part of its range, monitoring in British Columbia should begin immediately. Where densities are still relatively high, its ecology, natural history and metapopulation dynamics should be studied. Such information will be important in identifying the cause(s) of population losses and declines should they be identified elsewhere.

This report describes standard sampling and monitoring protocols for determining presence, estimating abundance, identifying individuals, and collecting diseased animals. The identification and protection of critical habitats, and means by which to document and monitor sources of mortality are also discussed. The importance of long-term monitoring and metapopulation structure at the regional scale is discussed in Section 4.

Various standard methods are available for monitoring and studying *B. boreas*. Determining presence can be done with 1) visual encounter surveys in terrestrial habitats; 2) surveys of ponds and lakes; and 3) night driving. Estimating relative abundance can be done with visual encounter surveys, counting the number of actively breeding adults, and visual counts of larvae and metamorphs. Mark-recapture is generally the most useful method for estimating abundance, and this requires identification of individual animals upon recapture. Individual identification can be done with PIT tags (passive integrated transponder tags) or pattern mapping. Toe clipping is not recommended because of the possibility of infection and subsequent mortality. Because of the possibility of spreading pathogens and parasites among populations, field equipment should be decontaminated before use at subsequent sites and care should be taken to avoid direct and indirect contact between captured animals. If dead or diseased toads are discovered during fieldwork, they should be sent to qualified laboratories for assessment. If mass mortality events are encountered, documentation should be as thorough as possible because most such events pass unnoticed and are seldom described.

Monitoring, research and management should be adaptive to take advantage of new information as it is

acquired. After determining presence, a monitoring program can begin, with the goal of detecting population trends. Typically, this is done by measuring relative abundance through time to estimate population fluctuations across years, but such an index of abundance should be calibrated with estimates of population size whenever possible. For trend data to be useful, corresponding environmental, historical, and biological information is needed. Monitoring must be done over the long term to detect meaningful trends. The detection of trends is complicated by a number of factors, including serial autocorrelations, population variability, and statistical issues.

If populations are to be protected and managed, critical habitats need to be identified. These include breeding ponds and wetlands, and terrestrial habitat used outside the breeding season. Adult toads spend the non-breeding season in a variety of habitats, including relatively dry upland mature forests, regenerating clearcuts, and wetlands. The movements and home range locations of adult toads outside the breeding season can range from 400 to at least 1600 m from breeding ponds, and can best be identified using radiotelemetry. Methods for studying the movements of aggregations of migrating juvenile toads need to be developed.

Adult toads are highly adaptable and utilize any habitat that has at least some accessible water and cover throughout the summer. Cover is probably important for maintaining a favourable water balance, behavioural thermoregulation, and protection from vertebrate predators. Construction of roads, houses, or dams can degrade or destroy both breeding and terrestrial habitats or create barriers to movements among them. Recent clearcuts (< 5 years) are probably unfavourable to both adult and juvenile toads, but as regeneration occurs and cover becomes available, clearcuts become very favourable habitats, especially for adult toads.

If a decline is detected, efforts to reverse the decline are seldom practical. Nevertheless, it is important to document and identify the probable causes of declines as this information could benefit populations elsewhere. Current understanding suggests that habitat fragmentation and degradation should be minimized, buffer zones around breeding sites should extend at least several hundred metres into terrestrial habitat, roads should not be built in the vicinity of breeding ponds, fish should not be introduced into breeding habitat, and connectivity among populations should be encouraged.

Many amphibian species have patchy spatial distributions and function demographically as a metapopulation. *B. boreas* probably exhibits metapopulation dynamics, but this has not been studied. In theory, if habitat is fragmented, or the number or size of populations is reduced, the risk of local extinction will increase and colonization rates will decrease. The disruption of such metapopulation dynamics can lead to regional extinction.

A comprehensive management and research program for *B. boreas* would include long-term monitoring of undisturbed local populations, monitoring for presence/absence at an expanded spatial scale, study of the causes of adult mortality, study of dispersal patterns of adult toads and metamorphs, and study of adult and juvenile habitat requirements. A multi-species approach to monitoring amphibian populations, at both a broad geographic level and studying a few populations intensively at a local level, is recommended. Amphibians are important to monitor and protect because of their considerable ecological importance and sensitivity to environmental change, and increasing public interest in their status and protection.

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# 1 INTRODUCTION

## 1.1 Declining Amphibian Populations

### 1.1.1 Global

Over the past several decades, many amphibian species have undergone population declines, range reductions, or extinction (Blaustein et al. 1994a; Blaustein et al. 1994b; Blaustein and Wake 1990, 1995; Green 1997; Wake 1998; Alford and Richards 1999; Carey et. al. 1999; Houlahan et al. 2000). Although some declines can be explained as natural population fluctuations, and a few are unexplained, most declines and disappearances are clearly the result of human activities – primarily habitat loss or degradation as the result of land conservation, urbanization, or development (Wake 1991; Vial and Saylor 1993; Corn 1994; Blaustein and Wake 1995; Pechmann and Wake 1997; Lehtinen et al. 1999). Other factors, including the introduction of exotic vertebrate species, infection with viral, fungal, bacterial, or invertebrate pathogens, harvesting by humans, road mortality and habitat fragmentation also have contributed to amphibian declines. (*Exotic species*: Hayes and Jennings 1986; Bradford 1989; Gamradt and Kats 1996; Kiesecker and Blaustein 1997, 1998; Lawler et al. 1999; Knapp and Matthews 2000); *pathogens*: Carey 1993; Blaustein et al. 1994c; Laurance et al. 1996; Hecnar and M'Closkey 1997b; Kiesecker and Blaustein 1997; Speare et al. 1997; Berger et al. 1998; Carey et al. 1999; Johnson et al. 1999; Taylor et al. 1999; Carey 2000; *harvesting*: Blaustein and Wake 1995; *road mortality*: van Gelder 1973; Fahrig et al. 1995; *habitat fragmentation*: Blaustein et al. 1994b; deMaynadier and Hunter 1995; Corn and Fogleman 1984; Sjögren 1991; Gibbs 1998a ; Sjögren-Gulve and Ray 1998; Lehtinen et al. 1999).

Some losses have occurred in relatively pristine habitats, and usually it is difficult to identify unambiguously the factors responsible in these cases (Carey 1993; Kagarise Sherman and Morton 1993; Corn 1994; Pounds and Crump 1994; Laurance et al. 1996; Lips 1998; Carey et al. 1999). Anthropogenic factors, such as acid rain, pesticides, and increased solar ultraviolet flux (as the result of the thinning of stratospheric ozone) have been suggested as possible causes, but clear evidence is sparse. In other cases, viral, fungal and bacterial diseases of unknown etiology have been implicated (Carey 1993; Laurance et al. 1996; Speare et al. 1997; Berger et al. 1998; Lips 1998; Carey et al. 1999).

### 1.1.2 Temperate-zone forests

In North American temperate-zone forests, the fragmentation, modification, or loss of habitat, primarily by forestry activities, is thought to have reduced amphibian diversity and abundance (for reviews see Corn 1994; deMaynadier and Hunter 1995; Davis 1999). Most studies have focused on short-term effects, which generally result in a reduction of amphibian numbers soon after harvesting (Ash 1988, 1997; Raphael 1988; Welsh 1990; Corn and Bury 1991; Welsh and Lind 1991; Petranka et al. 1993; deMaynadier and Hunter 1995; Dupuis et al. 1995; Davis 1997, 1998; Dupuis 1997; Harpole and Haas 1999; Herbeck and Larsen 1999; but see Brooks 1999). Logging often produces even-aged stands which differ from older mature forests with respect to the size and decay state of coarse woody debris (CWD), foliage density, and species composition. These factors can lower densities of amphibians over most rotation periods (Dupuis et al. 1995; ; Harpole and Haas 1999; Herbeck and Larsen 1999; Waldick et al. 1999). Also, streams in logged stands can experience increased sedimentation, which results in smaller substrata, and this can reduce both abundance and diversity of stream-dwelling amphibians (Bury and Corn 1988; Corn and Bury 1989). However, the long-term consequences of forestry activities for most species of amphibians are still poorly understood.

Temperate-zone forests also have been reduced in size and fragmented by agricultural and urban development (Corn 1994; Olson et al. 1997). In particular, roads subdivide continuous habitat, disrupt metapopulation dynamics, and are the source of considerable amphibian mortality (van Gelder 1973; Harris and Silva-Lopez 1992; Schonewald-Cox and Buechner 1992; Fahrig et al. 1995; Gibbs 1998a). Land conversion, urbanization, livestock grazing, hydroelectic projects, recreation, and the introduction of exotic species have resulted in the loss and degradation of wetlands that are critical habitat for

amphibians (Corn 1994; Lind et al. 1996; Semlitsch and Brodie 1998; Lehtinen et al. 1999).

### 1.2 Natural History of the Western Toad

The Western Toad (*Bufo boreas*) occurs from southern Alaska to Baja California and as far east as Colorado and Utah (Stebbins 1954, 1985). Although wide ranging, its distribution is patchy. Historically, it has been found throughout British Columbia (including the Queen Charlotte Islands and Vancouver Island), except for the far northeast of the province (Green and Campbell 1984; Corkran and Thoms 1996; Green 1999). However, its current distribution, abundance, and population trends in British Columbia are largely unknown.

Mating takes place during daylight hours in lakes and ponds, but also in sloughs and quiet pools along rivers, and may occur anytime from late January to July depending on environmental conditions (Mullally 1952; Metter 1961; Black and Brunson 1971; Nussbaum et al. 1983, Olson 1988; Blaustein et al. 1995b; Muths and Corn 1997). In British Columbia, the earliest mating probably takes place on Vancouver Island in April. Males usually arrive first at breeding sites, and once the females arrive, mating is often completed within a week (Samollow 1980; Nussbaum et al. 1983; Olson et al. 1986; Olson 1988). There is no advertisement call (Black and Brunson 1971; Nussbaum et al. 1983; Olson 1992). Males will amplex with both male and female toads, but they will release males that give a release call (Black and Brunson 1971; Marco et al. 1998). Toads will home to breeding ponds when displaced up to 200 m away (Tracy and Doyle 1969).

Eggs are laid communally in gelatinous strands several metres in length, each female producing an average of 12,000 eggs (Samollow 1980; Blaustein 1988). These egg masses are subject to UV damage and subsequent infection by the pathogenic fungus *Saprolegnia ferax* (Blaustein et al. 1994a,c; Kiesecker and Blaustein 1995, 1997; but see Licht 1996). Embryos develop rapidly, and emerge within 1 week to 10 days, depending on water temperature.

Western Toad tadpoles are typically found schooling in the sun in shallow water where temperatures are relatively high. Here their black bodies absorb light, which is radiated as heat, further increasing local water temperature. These high temperatures result in accelerated growth and development. *Bufo boreas* tadpoles can form huge temporary aggregations, sometimes containing millions of individuals. Various aquatic organisms, but not fish, prey on the tadpoles (Peterson and Blaustein 1992; Kiesecker et al. 1996; Jones et al. 1999). Four captive mallard ducks (*Anas platyrhynchos*) consumed 200 *B. boreas* tadpoles in less than one minute (Jones et al. 1999), suggesting that waterfowl might be important predators in nature. Gray Jays (*Perisoreus canadensis*) have also been observed feeding on *B. boreas* tadpoles (Beiswenger 1981).

In the summer, tadpoles synchronously transform into toadlets (= metamorphs; juvenile toads recently transformed from tadpoles) about 2-3 months after the eggs are laid (Olson et al. 1997; T. Davis unpublished data). Typically, thousands of toadlets can be observed basking and feeding at the edges of ponds (Lillywhite et al. 1973; Carey 1978). At the time of the metamorphic climax, both tadpoles and toadlets are especially vulnerable to predation because their ability to escape by either swimming or jumping is compromised as the result of developmental changes (Huey 1980). Garter snakes (*Thamnophis sp.*) are important predators on toadlets, and synchronous metamorphosis may reduce predation pressure by predator satiation (Arnold and Wassersug 1978; Devito et al. 1998). Spotted Sandpipers (*Actitis macularia*) and American Robins (*Turdus migratorius*) have also been observed preying on toadlets (Jones et al. 1999). Over a period of several weeks, toadlets disperse away from their natal lake or pond into terrestrial and wetland habitats. They take from 4-6 years to reach sexual maturity, and can live to at least 11 years (Olson 1988, 1992; Carey 1993).

As a defense against predators, adult toads have glands that produce toxic skin secretions. Despite this, they are vulnerable to predation by some reptiles, birds and mammals, especially during the breeding period. Adult toads have been found in the stomachs of the Common Garter Snake (*Thamnophis sirtalis*) (P. Gregory, pers. comm.). Crows, ravens and other passerine birds also are known to prey on adult toads (Olson 1989, 1992; Corn 1993; Kagarise Sherman and Morton 1993; Brothers 1994), as are various small

mammals including Racoons, skunks and foxes (Corn 1993; Jones et al. 1999). Jones and Stiles (1999) reported predation on toads by the Red-Tailed Hawk (*Bueto jamaicensis*). Toads are opportunistic feeders on a variety of invertebrates (Schonberger 1945; Livezey 1961; Clarke 1974; Barrentine 1991) and will occasionally eat small vertebrates (Cunningham 1954; Hansen and Thomason 1991).

Outside the breeding season, toads live in a wide variety of terrestrial and wetland habitats, including forests, open meadows and marshes. Terrestrial home ranges during the summer can be at least 1 km from breeding ponds, and probably further (Campbell 1970; T. Davis, unpublished data – see section 3.3). Other species of *Bufo* move similar distances from breeding ponds into terrestrial habitats (Sinsch 1988a; Dodd 1996). Home range size is typically about 1 ha or less, and toads are remarkably philopatric, as demonstrated by frequent recaptures and experimental displacements of up to 1 km (T. Davis, unpublished data). Home range fidelity is common in this genus (Carpenter and Gillingham 1987; Sinsch 1988a). Within their home ranges, individuals have favoured microsites where they can be recaptured repeatedly (T. Davis, unpublished data).

Adult toads can be found basking diurnally on logs at the edges of ponds and lakes, especially, but not exclusively, during the breeding season (Muths and Corn 1997). However, most adult toad activity occurs at night (Mullally 1952; Lillywhite et al. 1973; Hailman 1984; T. Davis, unpublished data). Hailman (1984) found that nocturnal activity in the North Cascades (Washington, USA) was bimodal with peaks about 3 hours before and after midnight in the summer. This suggests that illuminance is critical in controlling toad activity, but temperature and moisture are also important. Toads are active throughout the year as long as temperatures are greater than 3 °C, but during the winter toads become relatively inactive and avoid freezing temperatures by occupying rodent burrows and other underground retreats (Mullally 1952; Campbell 1970). In late summer when conditions are dry, toads are relatively inactive and remain in moist terrestrial microhabitats or in water (T. Davis, in prep.).

Because of declines and local extinctions over much of its range in the United States (Corn 1994), *B. boreas* is yellow-listed as a species of conservation concern in British Columbia and is the only IUCN red-listed amphibian in Canada (http://www.unep-wcmc.org, http://www.redlist.org).

### 1.3 Decline of the Western Toad in Western North America

There is abundant evidence that population declines and local extinctions of *B. boreas* have occurred throughout much of the southern part of its range. Corn et al. (1989) failed to *find B. boreas* at 49 of 59 (83%) historical sites in Colorado and Wyoming in 1986-1988, although toads were found at two sites where they had not been recorded previously. Carey (1993) reported that 11 populations of *B. boreas* disappeared between 1974 and 1982 in central Colorado. Additional surveys in Colorado have found fewer populations than existed previously (Corn and Vertucci 1992; Corn 1994). Livo and Yeakley (1997) reported a possible reduction in the elevational range of breeding sites in Colorado and Wyoming. Olson (1992) described declines of two populations of *B. boreas* in the Oregon Cascades, and Blaustein and Olson (1991) described mass mortality of toad eggs at a third site. In Yosemite National Park, surveys in 1915 and 1919 described *B. boreas* as "exceedingly abundant", but only small numbers were found in 1992, and of eight historical sites, *B. boreas* was found at only one (Drost and Fellers 1996). Similarly, Fisher and Shaffer (1996) described the decline of *B. boreas* in the Sacramento and San Joaquin Valleys, California. Disease, habitat modification, susceptibility to UV radiation, acid precipitation, and predation have been suggested as possible causes for the declines, but unequivocal evidence is lacking (Corn et al. 1989; Olson 1989, 1992; Corn and Vertucci 1992; Carey 1993; Blaustein et al. 1994a,c; Corn 1994).

Despite these reports from the United States, there are no published reports of population trends in Canada. At Jordan Meadows on southern Vancouver Island, British Columbia, where toads were very abundant in 1975-1979, Davis and Gregory (in prep.) failed to find any toads during intensive searches in 1997–2000. Anecdotal reports indicate that *B. boreas* populations have declined elsewhere on Vancouver Island (T. Davis, unpublished data). The reasons for

these declines on Vancouver Island are unknown, but may be related to habitat fragmentation, introduction of exotic fish, or disease.

### 1.4 Objectives

The overall objective of this report is to outline research priorities for the management of the Western Toad in British Columbia. Effective management is reduced to guesswork without basic natural history and long-term baseline abundance data. Because *B. boreas* has suffered dramatic population declines over much of the southern part of its range, and little information exists on population trends in British Columbia, monitoring this species in British Columbia should begin immediately. Where densities are still relatively high, an opportunity exists for studying the ecology, natural history and metapopulation dynamics of this toad. Such information will be important in identifying the cause(s) of population losses and declines should they be identified in British Columbia.

This report describes standard sampling and monitoring protocols for determining presence, estimating abundance, identifying individuals, and collecting diseased animals. Monitoring and research issues that are likely to arise in the management of local populations are also discussed. These include the identification and protection of critical habitats, and means by which to document and monitor sources of mortality. Finally, discussion of the importance of long-term monitoring and metapopulation structure at the regional scale is included.

## 2 RESEARCH AND MONITORING PROTOCOLS

### 2.1 Standardization

Without standard methods it is very difficult to assess patterns of population fluctuations or to determine appropriate management action because observations made in different ways at different times or places are not necessarily comparable. Thus, standardization of data collection is critical in monitoring and inventory programs, especially where the objective is to determine population trends and status (Vial and Saylor 1993; Heyer et al. 1994; Olson et al. 1997). Simply using approximately the same methods, however, will not insure that the results are comparable. For example, apparent toad abundance, determined by night searches along roads, can vary with the time of night, recent weather conditions, season, or year, independent of the actual abundance (T. Davis, unpublished data). Thus, it is important that methodological assumptions are clearly understood, sufficient sampling effort undertaken, and the details reported.

The primary reason for using standard methods is to allow for meaningful comparisons of population parameters among years or locations. However, overly strict adherence to standard protocols might fail to adequately address the objectives of the study or might be impractical to implement. Some flexibility in the application of standard methods is necessary so as to adapt them to particular objectives and circumstances.

When possible, a variety of methods should be used (Heyer et al. 1994). This will increase confidence in the results, and will help identify which methods are most informative. Because a variety of methods are "standard", using more than one will facilitate comparison with other studies.

### 2.2 Determining Presence

The range of *B. boreas* includes nearly all of British Columbia, but like many amphibian species, its local distribution is patchy. Thus, the fist step in the management of *B. boreas* at a local scale is to determine where it is present. Historical records and local knowledge can used to focus searches, but historical distributions may have changed and populations or breeding activity may have been overlooked, so all potential habitat should be surveyed. Establishing presence is usually most efficiently done as part of a multispecies inventory, and this should be undertaken wherever amphibian populations are of interest (Davis 1999). There are a wide variety of inventory methods available for amphibians (Heyer et al. 1994; Olson et al. 1997), but certain protocols are more appropriate for some species than for others. For *B. boreas*, presence can most efficiently be established by 1) visual encounter surveys in terrestrial or semi-terrestrial habitats, 2) surveys of ponds and lakes, and 3) night driving.

Visual encounter surveys involve walking through habitat for a prescribed time period searching for

amphibians, and is appropriate for a wide variety of amphibian species (Heyer et al. 1994). Although most adult toad activity occurs at night, adult toads can often be seen during daylight, especially where densities are high or during the breeding season. Favoured habitats include meadows, shallow emergent wetlands, and the edges of lakes and ponds.

Searching under natural cover (e.g., under bark or logs on the ground, in burrows or rock crevices) is a standard technique for herpetological inventories, and toads can sometimes be located in this way. Toads often seek cover during daylight, especially when conditions are dry, so searching under natural cover might prove to be a useful technique under certain conditions. However, this is generally not the case, and the other methods described here are usually more cost-effective. Nevertheless, searching under natural cover is frequently essential in multispecies inventories because some species rarely can be found by other means.

During the breeding season, adult toads congregate at breeding sites and densities are relatively high. They are especially visible at this time because they are active during daylight hours and frequently can be seen basking on logs or on the water surface. Therefore, lakes and ponds should be searched carefully during the breeding season for adult toads. After breeding, the adult toads typically disperse away from lentic habitats, but *B. boreas* tadpoles are relatively easy to see and identify. Later in the summer when the tadpoles transform, the metamorphs are concentrated and evident along the shoreline.

There is considerable variation in the timing of these events among years and sites, but the search methods are essentially the same at any time in the spring and summer. Overcast days should be avoided because adult toads may not be basking, tadpoles may congregate in deeper water if the surface water is cold (Beiswenger 1977), and metamorphs may be relatively inactive and under cover objects. During the short breeding season, adult toads can be seen on the water surface, or basking on logs or in vegetation at the water line, so these areas should be carefully scanned with binoculars. This should be done when first approaching the pond, because toads may hide if disturbed. Next, if conditions allow, the entire waterline should be searched by walking along it while looking for toads or tadpoles, stopping occasionally to scan with binoculars. If tadpoles are present, they often can be seen schooling in shallow water near shore. Tadpoles generally cluster in the warmest water available, which during the day is typically in shallow, protected water, and often in emergent vegetation. At the time of metamorphosis, and for a few weeks afterwards, metamorphs can be found within a few metres of the water line. Similar searches for tadpoles can be done by wading in shallow water. Canoes, kayaks, and other small boats can be used to survey deeper water, and work especially well if fitted on the bottom with a clear plastic underwater viewing plate. Under certain lighting conditions, tadpoles near shore can be seen more easily from a boat than from shore. Boats are also useful for gaining access to shorelines that are difficult to access by land. Tadpoles can sometimes be detected by snorkelling when other methods fail, especially on overcast days. Additional suggestions can be found in Olson et al. (1997).

Night driving is an especially effective method of finding adult toads outside the breeding season. Night driving is advantageous in that relatively large areas can be surveyed, as long as roads are present. Searches can be done at anytime of the year, but toads are most likely to be found when temperatures are high and conditions wet. However, heavy rain or wind may reduce encounter frequency. Although toads can be captured throughout the night, the most efficient strategy is to search from just after dusk to midnight. Unpaved roads should be driven at about 10-20 kph, and in this way 20 km of road can be surveyed twice in about 3 hours. Extra search lights mounted on the front of the vehicle greatly improve spotting efficiency, especially on gravel roads were stationary toads can be hard to distinguish from rocks and debris. Shaffer and Juterbock (1994) recommend cruising speeds of 20 to 35 kph, and this is appropriate for paved roads. However, there is considerable mortality on toads from motor vehicles, so populations are likely to be depressed where there is frequent night-time traffic. Additional recommendations can be found in Shaffer and Juterbock (1994).

These methods for establishing presence are suitable for a variety of amphibian and reptile species. Because both travelling to sites and searching can be expensive

and time-consuming, multispecies surveys are highly recommended (Davis 1999). Visual encounter surveys and night driving can establish the presence of many species of anurans, and some species of reptiles. Some amphibian larvae are difficult to identify in the field, but keys are available (e.g., Corkran and Thoms 1996), and with some training and experience it is possible to make positive identifications. Where identifications are uncertain, voucher specimens can be taken and sent to the appropriate taxonomists. Methods for collecting and preserving voucher specimens can be found in Heyer et al. (1994). Adding searches of course woody debris and other cover objects to the survey effort is highly recommended because it will include the strictly terrestrial amphibian species and most reptiles, and will increase the chances of detecting pond-breeding amphibians outside the breeding season. For terrestrial amphibians, these methods are described in RIC (1999). For reptiles, see Gregory and Campbell (1984).

### 2.3 Estimating Abundance

For estimating the relative abundance of *B. boreas*, several complementary approaches are available. These include visual encounter surveys of terrestrial and semi-aquatic habitat, counting the number of breeding adults, and visual counts of larvae and metamorphs. Data from visual encounter surveys is typically summarised as the number of animals observed per unit time (e.g., 1 h). Time should be calculated as the total time actively spent searching by all observers, not including other activities such as processing animals (e.g., weighing and measuring). Alternatively, the number of animals found per unit area (for open areas such as meadows) or linear distance (e.g., along streams, the edges of lakes, roads) can be used as indices of abundance. During the breeding period, the number of adult toads can be counted at breeding sites, including the number of amplexing pairs. This requires frequent visits to known breeding sites during the breeding period because peak activity is synchronous over a period of just a few days. Thus, very intensive surveys are appropriate during that period. Counts of larvae and metamorphs can be done later in the year. However, estimating of the number of tadpoles or metamorphs can be time-consuming, and should not be undertaken unless the effort can be sustained and justified as part of a long-term monitoring effort (see section 4.2).

There are various methods for sampling amphibian larvae (see Shaffer et al. 1994; Olson et al. 1997), but because *B. boreas* tadpoles tend to school, specialized methods may be appropriate. The choice of methods will depend on tadpole density, pond depth and size, and the amount of emergent vegetation. One approach is to stratify the pond and count the number of tadpoles in sample quadrats (e.g., 1x1 m), either as visual counts or with a metal box sampler (Shaffer et al. 1994). However, if tadpoles are schooling in a long string, it will be more efficient to count the number of tadpoles in sample quadrats along the string and multiply by the total length of the string. It is sometimes difficult to count *B. boreas* tadpoles because the densities within a quadrat can be very high, and the tadpoles move around. These problems can be partially overcome by photographing the quadrats and later counting the number of tadpoles in the photographs. A reference scale can be placed in the school, or the tadpoles themselves can be used as a scale. A combination of these approaches may give the best results. Detailed notes should be made of how the sampling was done so that comparisons can be made with other estimates. More than one visit to a site is required because the behaviour and visibility of tadpoles will vary depending on weather conditions.

Similarly, the number of metamorphs can be estimated on land. For consistency among years, sampling should be done just after the metamorphic climax, when the number of toadlets has peaked. Sampling should be continued until it is clear that toadlets are dispersing and their numbers at the breeding site are decreasing. Stratification is often appropriate. Typically, areas can be conveniently marked off with flagging on metal wire stakes. Because toadlet densities are often too high to permit easy measurement of these areas, they can be measured later after the toadlets disperse. An additional difficulty is that metamorphs will scatter as they are approached. This can be overcome by photographing quadrats with a camera fitted with a remote trigger. The camera is set up on a tripod over the quadrat to be photographed, and the shutter tripped after the toadlets move back under the camera.

Various standard methods are available for estimating population size (Krebs 1989; Heyer et al. 1994; Thompson et al. 1998). These include mark-recapture, removal sampling, and complete census. Of these methods, mark-recapture methods using multiple samples are generally the most useful, and these require identification of individual animals upon recapture (see next section).

### 2.4 Individual Identification

Individual identification is essential for estimating abundance from multiple samples, and is often necessary for estimating growth rates, age at sexual maturity, frequency of reproduction, survivorship, and other life history parameters (Krebs 1989). There are a wide variety of identification and marking methods available for amphibians including toe-clipping, tattooing, branding and tagging (Ferner 1979; Donnelly et al. 1994). Because it is inexpensive and easy to do, toe-clipping (i.e., excising a unique combination of toes from each individual) is commonly used in amphibian studies, but toes can regenerate and the marks are not necessarily permanent (Ferner 1979; Donnelly et al. 1994; Halliday 1994). Also, effects of toe-clipping on the survival, behaviour, and recapture rates have received little attention, although some evidence suggests that morbidity or mortality may be significant (Clarke 1972; Daugherty 1976; Golay and Durrer 1994; Reaser 1995; Halliday 1994, 1995; Davis and Ovaska, 2001). For example, Clarke (1972) found an inverse correlation between the number of toes excised and the recapture rate of Fowler's Toad (*Bufo woodhousei fowleri*), suggesting that toe-clipping either affected behaviour or reduced survivorship. Golay and Durrer (1994) reported that 18% of toe-clipped Natterjack Toads (*Bufo calamita*) suffered infection and necrosis, sometimes involving the entire limb. For these reasons, toe-clipping should be avoided unless the toes are needed for molecular studies or skeletochronology (e.g., Friedl and Klump 1997; Sagor et al. 1998).

PIT tags (passive integrated transponder tags) are suitable for adult toads. These are small (12 x 2.1 mm) transponders sealed in glass and may be injected into the body cavity of animals weighing >10g (Donnelly et al. 1994; Ott and Scott 1999). The tags are read with a hand-held scanner which energizes the transponder causing it to transmit a unique 10-digit alpha-numeric code that is displayed on the scanner screen. The main disadvantages of PIT tags is that they are expensive ($7 – $9 CND per tag, $700 – $1400 CND or more for the scanner; Donnelly et al. 1994; Reaser 1995; Ott and Scott 1999), may be less reliable than generally presumed (reviewed in Jemison et al. 1995), and their effects on mortality, morbidity and behaviour are largely untested. Nevertheless, PIT tags may be a practical option for some studies.

Pattern mapping (i.e., identification of individuals based on natural, existing variation in colour patterns and other markings) is the least invasive method of individual identification (e.g., Hagström 1973, Andreone 1986; Donnelly et al. 1994; Doody 1995). In *B. boreas*, the shape of the dorsal stripe and the pattern of warts on the dorsal surface can be used effectively. Either a conventional camera or a digital camera can be used to photograph individuals. The photographs can be arranged in an atlas, and stratified by arbitrary but convenient criteria. For example, stratification could be based on the number of warts touching the dorsal stripe on the head and then further subdivided by, for example, the number of warts on the right forelimb. By this means a few hundred animals can be monitored. More formal development of this technique with digital analysis could potentially accommodate a thousand or more animals.

### 2.5 Disease and Mortality Protocols

#### 2.5.1 Preventing the spread of disease

Infectious diseases are of increasing concern with respect to declining amphibian populations and wildlife in general (Carey et al. 1999; Carey 2000; Daszak et al. 2000). Because amphibian pathogens and parasites can be inadvertently spread among sites by fieldworkers, the Declining Amphibian Population Task Force (DAPTF) has developed a fieldwork code of practice (www.npwrc.usgs.gov/narcam/techinfo/daptf.htm). Footwear, nets, containers, boats and other equipment should be decontaminated before use at subsequent sites by removing mud and other debris and scrubbing with either 70% ethanol or bleach. However, care must be taken not to contaminate a pond or wetland with the

disinfectants. Disposable gloves and containers should be used when handling rare or isolated species, and care should be taken to avoid direct and indirect contact between captive animals. Amphibians also can pick up novel disease agents in captivity which upon release of the captive animals could spread to wild populations. Thus, contact between animals from different sites should be avoided, animals should not be brought into contact with plants or unsterilized soils from other sites, and disposable or disinfected gloves, containers and other equipment should be used routinely. Although these measures may appear to some to be extreme, the numerous instances where disease has been implicated in amphibian mortality has led to the recommendation of these precautions by DAPTF and others (e.g., Livo and Jones 2000).

### 2.5.2 Collecting dead toads

If dead or diseased toads are discovered, they should be sent for assessment to laboratories that are able to determine the probable cause of death, including the capability to detect chytrid fungi (e.g., University of Saskatchewan, Western College of Veterinary Medicine, Veterinary Pathology, Saskatoon, Saskatchewan). Preferably, dead animals should be frozen, but alternatively, they can be preserved in formalin. Sick animals should be collected and monitored and taken or sent to a herpetologist or veterinarian experienced in amphibian diseases. In all cases, the receiving institution or individual should be contacted before sending specimens.

The Boreal Toad Recovery Team (Colorado Division of Wildlife, Fort Collins, Colorado) has developed an "amphibian death kit" for the field collection of dead amphibians (Livo and Jones 2000). This kit consists of disposable gloves, suitable containers for collecting specimens, concentrated formalin, labels, pens and pencils, and an instruction sheet. These kits are intended for wildlife and conservation personnel who work primarily with other taxa, but who might opportunistically observe amphibian mortality. Where toads are frequently encountered in British Columbia, a similar program might be appropriate.

Mass mortality events are rare, so if encountered, documentation should be as thorough as possible because most such events pass unnoticed and are seldom described. Photographs of the dead animals and surrounding habitat should be taken, and the number of dead animals should be estimated. Dead or sick animals should be collected (as described above). A water sample should be taken if the event is associated with a pond or wetland. Precise location, weather conditions, temperature and any other relevant observations should be recorded.

## 3 MONITORING AND RESEARCH PRIORITIES FOR MANAGEMENT OF LOCAL POPULATIONS

### 3.1 Adaptive Management

The ultimate goal in most monitoring programs is to detect population declines should they occur. Combined with environmental information, reasons for the declines might be identified, and steps might be taken to reverse downward trends and protect populations not yet affected. Because our understanding is limited and ecosystems complex, management and research activities should be flexible, adaptive, and minimally intrusive (Meffe and Carroll 1997). This means that as experience and new information is acquired, management plans and research priorities should be modified or developed in creative and innovative ways. This does not mean that goals and research questions can be vague, but rather that flexibility must be built into programs to take advantage of new knowledge as it becomes available.

### 3.2 Monitoring Local Populations

The first step in the management of local populations is to establish where toads are found and especially where they are breeding (section 2.2) Once this is done, a monitoring program can be started with the goal of detecting population trends. Typically, this is done by measuring relative abundance through time to estimate population fluctuations across years. Measures of relative abundance are attractive, because compared to more precise estimates of population size, they are relatively inexpensive and easy to obtain. However, indices of abundance can have a high sampling variance, be biased across space and time with respect to the actual abundance, and either mask

trends or suggest trends where none exist (Thompson et al. 1998). The fundamental problem with using indices of abundance alone is that the relationship between indices and population size are often not linear and may change. Therefore, it is important to calibrate indices of abundance with estimates of population size whenever possible. If costs are prohibitive, measures of relative abundance are still useful, but the results must be treated with caution.

Setting up a complete monitoring program is complex (Thompson et al. 1998). Obviously, effort is wasted if surveys are inadequate and no solid conclusions about populations trends can be made. For example, if the data are insufficiently precise to detect a trend and statistical power is low, failure to detect a trend cannot be used as evidence that there is no trend (Gerrodette 1987; Reed and Blaustein 1995). To detect meaningful trends, monitoring efforts need to span many years or decades because trends over shorter periods of time might simply be the result of stochastic or other population fluctuations. Successful monitoring efforts require adequate sample sizes and a sampling effort that can be maintained over the long term (years to decades). Again, indices of relative abundance can be used, but these should be used cautiously and supplemented with reliable estimates of population size.

Trend data are not particularly useful without corresponding environmental, historical, and biological information. This includes meteorological and hydrological data, documentation of human activities such as road construction, forestry, fish stocking or other activities, and habitat and natural history observations. Such data are usually collected concurrently with population data, and should be published or stored in a permanent repository.

The amount and quality of data that are collected will depend on the management goals, and cost and time considerations. Some data, such as the numbers of individuals, life-history stage, location, temperature and weather conditions, are easily recorded, but the usefulness of data that are time-consuming to obtain should be critically evaluated. For example, weighing and measuring individual animals can be time-consuming, and unless the data are to be analyzed later, there is no point in recording these measurements. Similarly, detailed vegetation plots are of little use if it is unclear how they are to be analyzed with respect to abundance data.

Some environmental data require very little time to collect, are easy to collect, and are likely to be useful. For example, once a reference point is established, changes in the water level of breeding ponds could be easily recorded. Standard meteorological observations can be taken during surveys and include air and water temperatures, and qualitative estimates of precipitation, wind strength, and cloud cover (Olson et al. 1997). Nearly continuous temperature monitoring is possible with relatively inexpensive data loggers, and these can be used in both terrestrial and aquatic environments. For example, water temperatures in a pond could be monitored at various depths (e.g., in shallow water near the shoreline, and in deeper water at depths of 10 cm, 1 m, and 5 m) and such data could be very useful in explaining variation in the timing of breeding, tadpole development and behaviour, and other phenomena of interest. Air temperatures could be monitored simultaneously. Similarly, quantitative measurement of precipitation could be recorded with automated systems.

### 3.3 Critical Habitats

One of the key problems with respect to managing amphibian populations is the identification of habitats that are essential for the survival of individuals and species (critical habitats). Because of the diversity of natural history characteristics, habitat requirements, and tolerances to environmental variables among species, it is often difficult to determine which habitats need to be protected and in what manner. For toads (and other pond-breeding amphibians), breeding ponds and wetlands are obviously necessary for persistence. The terrestrial requirements, however, are little studied (Dodd 1996).

Outside the breeding season, adult toads use terrestrial and aquatic habitats away from breeding sites. On Vancouver Island, Davis (in prep) found that both the habitat type and distance from potential breeding sites varied hugely among individuals. Some adult toads spent the non-breeding season in relatively dry upland mature forests, many were found in regenerating forests (e.g., >10 year-old clearcuts), but others inhabited marshy wetlands. The distances from presumed breeding sites ranged from 400 to 1600 m.

One toad was radiotracked 150 m to a wetland from its known breeding pond and another was found at least 1000 m from its known breeding pond. Movements along watercourses can be greater, and one toad was observed to move 7.2 km in less than two months (Davis, in prep). These values are consistent with observations of overland movements of other anurans under natural conditions (Sinsch 1988b; reviewed in Dodd 1996).

Adult toads are highly adaptable and appear to utilize any habitat that has at least some accessible water and cover throughout the summer. Moisture is available to toads as standing or running water, or from wet soil in depressions, gullies, rodent burrows, or roadside ditches. Cover is probably important for both behavioural thermoregulation and protection from predators such as birds and small mammals. Human activities such logging, mining, and construction of roads, houses, or dams can degrade or destroy both breeding and terrestrial habitats or create barriers to movements among them (Schonewald-Cox and Buechner 1992).

In forested landscapes, recent clearcuts (< 5 years) are probably unfavourable to both adult and juvenile toads, although direct evidence is lacking. For adult toads, lack of cover increases water loss, reduces the range of temperatures that are available for behavioural thermoregulation in the summer, may expose them to below-freezing temperatures in the winter, and might lead to increased predation rates. Juvenile toads and metamorphs, because of their relatively small size and large surface to volume ratio, are much more subject to desiccation than are adult toads, and when in aggregations, they may be especially attractive to avian predators (Jones et al. 1999). Thus, because of the lack of cover in recent clearcuts, both adult and juvenile toads probably experience increased mortality rates, and these areas might represent significant barriers to dispersal. However, as regeneration occurs and cover becomes available, clearcuts become very favourable habitats, especially for adult toads. In particular, greater opportunities for behavioural thermoregulation exist than in forested areas (T. Davis, unpublished data).

To identify local habitats and sites used by adult toads, various complementary approaches are possible. Adult toads can be easily captured at breeding sites because they are aggregated and conspicuous. Once captured, they can be identified by pattern mapping (or marked or tagged – see section 2.4) and later recaptured at terrestrial sites (e.g., by night driving along roads – see section 2.2). Conversely, adult toads can be captured in terrestrial habitats and later identified at breeding sites. Probably the most effective and efficient means by which to identify critical habitats is to follow the movements of toads with radiotelemetry (radio tracking). Radiotelemetry can help identify habitats and locations that might otherwise be overlooked, determine the paths by which toads move between locations, and can be used to investigate a variety of ecological questions including microhabitat use in relation to microhabitat availability, home range sizes, movement patterns, and daily and seasonal activities (van Gelder et al. 1986; Werner 1991; Aebischer et al. 1993; Richards et al. 1994; Rathbun and Murphey 1996).

Because metamorphs and juvenile toads suffer high rates of mortality, cannot be radiotracked, and are small and cryptic, critical habitats used by them are more difficult to identify than those of adult toads. As metamorphs disperse away from their natal pond, densities become low and movements are difficult to follow. Despite this, dispersal by aggregations of toadlets can be followed considerable distances into terrestrial habitats. Such migrating aggregations have been observed at least 300 m from natal ponds (T. Davis unpublished data). Methods for studying the movements of such aggregations need to be developed.

From the above discussion it is clear that toads require not only the protection of known breeding sites, but also upland terrestrial sites that are difficult or impossible to identify without focused study. The breeding sites, terrestrial habitats, and habitats across which movements occur should be considered in any protection scheme. For example, breeding and terrestrial habitats may be protected, but if toads are crossing roads, the population may decline because roads can be a significant cause of mortality (van Gelder 1973; Fahrig et al. 1995).

### 3.4 Sources of Mortality

Populations may decline because of emigration, decreased recruitment, or increased mortality. Emigration is unlikely a direct cause of declining toad populations unless the habitat is extremely disturbed. Both decreased recruitment and increased adult and juvenile mortality can result from increased predation rates, disease, or road mortality. Although it may be important to identify these sources of mortality for explanatory purposes, practical measures for mitigating them locally can seldom be implemented once they are detected. Increased predation rates, as the result of an increase in the number of predators such as ravens and raccoons, may be a consequence of fragmentation and increased edge habitat. These predators can travel long distances, invade core areas, and decimate populations of both breeding adults and transforming toadlets (Groves 1980; Kagarise Sherman and Morton 1993; Olson 1989; Corn 1993; Jones et al. 1999), but little can be done once their populations are established. Such predators also might spread disease among toad populations, but this possibility has not been investigated. Once disease enters a population, it may be highly contagious, endemic, and impossible to control. If roads can be closed to vehicular traffic, especially at night and during the breeding season, some benefit to toad populations may result. However, road closures are seldom possible because of competing interests. Building "toad tunnels" under roads can reduce mortality under some circumstances, but not all such efforts have been successful. The best results will probably be obtained by installing fences along roads that funnel toads and other small vertebrates into tunnels.

Once a population begins to decline it may enter an "extinction vortex" in which the smaller a population becomes, the more vulnerable it is to demographic and environmental stochasticity and genetic problems, which in turn lead to even smaller population sizes (Primack 1998). As the population decreases in size these factors become increasingly significant, ultimately leading to extinction. Without immigration from elsewhere (see section 4.3), it is very difficult to reverse such a trend.

### 3.5 Conservation Measures

Despite our inability to take practical conservation measures in most circumstances once a decline has begun, it is still important to document the probable causes of the decline as this could benefit populations elsewhere. If we know why some populations have declined, we may be able to prevent the decline of other populations that are still robust by not allowing the predisposing conditions to occur. Although current understanding of toad population dynamics and habitat requirements is poor, information that we do have suggests that:

- habitat fragmentation and degradation should be avoided to minimize the amount of unsuitable habitat and the numbers of edge-favored predators;
- buffer zones around lakes, wetlands and other aquatic habitats should extend at least several hundred metres from the shore edge to allow for dispersal of metamorphs and movements of adult toads;
- because of the mortality associated with roads, they should not be built in the vicinity of breeding ponds;
- fish should not be introduced into breeding habitat because of the possibility of the introduction of fungal pathogens (Blaustein et al. 1994c, Kiesecker and Blaustein 1995, 1997); and
- connectivity among populations should be encouraged at larger scales because of the possibility of metapopulation dynamics (see section 4.3), although the presence of contagious disease would contraindicate such a strategy.

## 4 MONITORING AND RESEARCH PRIORITIES FOR MANAGEMENT AT THE REGIONAL SCALE

### 4.1 Population Declines

Population decline can refer to either: 1) reduction of the demographic sizes of populations; or 2) reduction of the absolute number of populations (Green 1997). Although these two types of declines are related, understanding and detecting them require two very different research and monitoring programs. Detection

of a demographic decline requires intensive monitoring of local population size, whereas detection of a decrease in the number of populations requires presence/absence data at many sites through time over a large area. In either case, monitoring must be done over the long term to detect meaningful trends.

### 4.2 Long-term Monitoring

Although some species of amphibians appear to have relatively stable populations (Hairston 1987), many species are subject to extreme variation in annual recruitment and population size and structure through time (Pechmann et al. 1991; Pechmann and Wilbur 1994). Natural variation in recruitment and population size depends not only on life-history traits, but on abiotic factors such as temperature and precipitation, and biotic factors such as disease, intra- and interspecific competition, prey abundance, and predation. Because these factors vary over time, so does the size of many amphibian populations. This makes it difficult to distinguish long-term trends from natural variation.

The detection of trends is complicated by a number of factors including serial autocorrelations, population variability, and statistical issues (McArdle 1989; Hanski 1990; Pechmann and Wilbur 1994; Hayes and Steidl 1997). Serial autocorrelations arise in two ways. First, the recruitment in any particular year will at least partly depend on the size of the breeding population. Thus, a large breeding population will tend to have a large recruitment, and a small breeding population will tend to have a small recruitment. Second, many environmental factors are autocorrelated, and because amphibian populations tend to track these factors, declines will often be followed by declines and increases by increases. Serial autocorrelation also increases the length of time it takes to detect the true variability of a population. The more variable the population size, the longer the population has to be monitored to detect the actual variation, and the harder it is to detect trends (Pechmann and Wilbur 1994; Hayes and Steidl 1997). Choosing a statistical approach for detecting population trends can be complex, and a power analysis should be done when the null hypothesis of no trend is not rejected (Gerrodette 1987; Pechmann and Wilbur 1994; Reed and Blaustein 1995; Hayes and Steidl 1997; Thompson et al. 1998).

Long-term routine monitoring is necessary if long-term population declines are to be detected should they occur. This is the only way to distinguish between natural population fluctuations and anthropogenetically induced population declines (Vitt et al. 1990; Pechmann et al. 1991; Blaustein 1994; Blaustein et al. 1994b; Pechmann and Wilbur 1994; Alford and Richards 1999). It is important to recognize that local population dynamics may not reflect regional trends (Green 1997; Alford and Richards 1999), and that monitoring needs to be done at an appropriate scale. Ideally this should be done over the entire known (or assumed) range.

### 4.3 Metapopulations

#### 4.3.1 Metapopulation ecology

Many plant and animal species that have patchy spatial distributions function demographically as a series of small populations that exhibit relatively independent population dynamics, but are linked by immigration and emigration. Such a network of local populations is known as a metapopulation (Hanski 1998, 1999; Alford and Richards 1999). When there is migration among local populations, each can persist longer than if they were isolated (the rescue effect), and if local extinction does occur, recolonization is possible from other local populations. Under these circumstances, the probability of extinction of the metapopulation will be less than the probability of extinction of any its local populations. Thus, because of the connectivity among local populations and their asynchronous population dynamics, a metapopulation can persist despite frequent local extinctions.

Both mathematical modeling and empirical studies of metapopulations have led to a number of important insights with respect to conservation biology (Hanski 1999). If habitat is destroyed – either by outright loss of habitat, fragmentation, or reduction of habitat quality – local populations will become smaller and more isolated. Because of their greater demographic variability, smaller populations will have greater probabilities of local extinction than larger populations, and isolated populations will have lower recolonization rates than

less isolated populations. Thus, habitat destruction will tend to increase the risk of local extinction and decrease colonization rates. This disruption of the balance between local extinctions and colonizations can lead to regional (metapopulation) extinction.

Metapopulation size (i.e., the number of local populations) is also important to persistence. Habitat destruction can reduce the size of a metapopulation both by reduction of the absolute number of local populations (or habitat patches) and by isolating groups of local populations through fragmentation. Just as smaller populations exhibit greater demographic stochasticity, smaller metapopulations exhibit greater extinction and colonization stochasticity. Also, in metapopulations with a small number of local populations, there is an increased risk of regional extinction because all local populations may happen to go extinct simultaneously (Hanski 1998). Thus, the metapopulation response to habitat destruction can be nonlinear, and rapid extinction may occur at some threshold level of habitat destruction. Alternatively, because the metapopulation response to habitat destruction can be subject to time lags, species may be found for long periods of time in landscapes that cannot support them in the long term (Tilman et al. 1994; Hanski 1998; Lehtinen et al. 1999). The delay is especially long when the original amount of undisturbed habitat is small and the colonization rate is low (as when patches are isolated).

Some of the key management lessons to be taken from the study of metapopulations are that 1) species may be absent from favourable habitat (because of stochastic extinction of local populations), but currently unoccupied fragments may be critical for long-term persistence, 2) species may be present where conditions are not favourable (sink populations), and 3) metapopulations are subject to time delays in response to environmental change and can be on a trajectory toward extinction despite their presence in modified landscapes (Hanski 1998). In terms of protected areas, habitat fragments should be located within the migration range of the species to allow recolonization, but far enough apart to behave as independent demographic units, thereby reducing synchronous regional stochasticity. For example, weather conditions or human activities might affect adjacent populations similarly and tend to synchronize population fluctuations, but more distant populations may experience these disturbances differently. Also, it is desirable to have dissimilar habitat patches among protected areas because they are unlikely to experience the most unfavourable conditions simultaneously or respond in the same way (Hanski 1998, 1999).

### 4.3.2 Metapopulations and *Bufo boreas*

Because of high rates at which individuals disappear from local populations and high dispersal rates among populations, metapopulations are thought to be common among amphibian species (Sjögren 199; Sinsch 1992; Alford and Richards 1999). Species mostly likely to function as metapopulations are those with good dispersal abilities and specialized habitat requirements, especially where those habitats are patchily distributed. Gibbs (1998b) found that forest fragmentation differentially affected amphibian species with good dispersal abilities and high habitat specificity, and Lehtinen et al. (1999) found that habitat loss and fragmentation decreased amphibian species richness, probably as a result of disruption of metapopulation dynamics. Also, direct evidence for metapopulation dynamics has been obtained for several amphibian species including the Red-spotted Newt (*Notophthalmus viridescens*; Gill 1978), the European Pool Frog (*Rana lessonae*; Sjögren 1991, 1994), the Natterjack Toad (*Bufo calamita*; Sinsch 1992) and the Green Frog (*Rana clamitans*; Hecnar and M'Closkey 1997a). In southern Ontario, Hecnar and M'Closkey (1996) found that ten other amphibian species, including *Bufo americanus*, exhibited population dynamics that suggest a metapopulation structure. Similar results have been found for 8 species in The Netherlands, including *Bufo bufo* (Laan and Verboom 1990). Bradford et al. (1993) found evidence that recent declines of the Mountain Yellow-legged Frog (*Rana muscosa*) in the Sierra Nevada of California was due to isolation of ponds and disruption of metapopulation dynamics as a consequence of the introduction of fishes.

Although there is no direct evidence that populations of *B. boreas* persist as a result of metapopulation dynamics, both theory and natural history data suggest

that a metapopulation structure might be typical for this species (Olson 1992; Ross et al. 1995; Robinson et al. 1998). Its patchy distribution, highly variable year-to-year reproductive effort and recruitment, and the ability of both metamorphs and adults to disperse over relatively long distances would favor a metapopulation structure. If metapopulation dynamics are important for the long-term viability of local populations, regional extinction could occur by the mechanisms described above.

Investigation of possible metapopulation dynamics in *B. boreas* is probably best addressed by using a multi-level approach that uses data on relative abundance and movements of individuals, but primarily identifies local extinctions and recolonizations by presence/absence data over a broad geographic scale. For example, Hecnar and M'Closkey (1997a) surveyed 160 ponds in southwestern Ontario for the Green Frog and were able to characterize patterns of occupancy, abundance, and turnover (colonization-extinction dynamics). They found that over a three-year period, extinctions took place at 25% of the ponds surveyed, but no subregional or regional extinctions occurred. If they had restricted their study to a local scale, they could have found the full range of possible results with populations increasing, decreasing, or stable. A similar effort could be undertaken for *B. boreas* in British Columbia.

## 5 SUMMARY OF RESEARCH AND MANAGEMENT PRIORITIES

A comprehensive management and research program for *Bufo boreas* would contain the following elements:

- **Long-term monitoring** – Long-term monitoring of undisturbed local populations is needed to determine the natural background variation in population parameters (Pechmann et al. 1991; Blaustein et al. 1994b; Pechmann and Wilbur 1994). This requires a modest effort at particular sites but a long-term commitment. Monitoring selected breeding sites for basic physical environmental parameters, the number of adult toads at the breeding climax, the extent of the egg masses, the number of tadpoles, and the number of metamorphs at the metamorphic climax, would require about two person-weeks in the field per year at each local population once the protocols were established. Such monitoring should done at several locations to characterize the variability in breeding success and other population parameters across entire the range of *B. boreas*.
- **Monitoring for presence/absence** – Monitoring for presence/absence at an expanded spatial scale is needed to detect metapopulation structure and dynamics. Also, it is necessary to determine the status of the species over a broad geographical area (Green 1997; Hecnar and M'Closkey 1997a). This would involve searching for toads and tadpoles at potential breeding sites and historic sites, and doing other searches as outlined in section 2. It is important to visit potential but unoccupied sites repeatedly because the absence of toads might be due to a temporary local extinction and recolonization may occur. This information, when compared with historic data, would give a rough indication of the current status of *B. boreas* in British Columbia. However, a one-time effort will not give the rate of population turnover and other important information, and because historic data are seldom collected systematically, interpretations must be provisional (Hecnar and M'Closkey 1997a). Thus, a truly useful monitoring effort must be done systematically at both an expanded spatial scale and over the long term.
- **Survivorship of adult toads** – Breeding adults in the spring represent the critical life-history stage with respect to persistence of populations (Green 1997). Therefore, causes of adult mortality are of considerable conservation interest. Likely causes of adult mortality include predation by birds and mammals, disease, and road mortality.
- **Dispersal** – The study of dispersal patterns of adult toads and metamorphs, especially with respect to movements to new breeding sites (see Breden 1987), is relevant to metapopulation parameters including maximum dispersal distance and population isolation (Sjögren 1991; Sjögren-Gulve 1994; Hanski 1998, 1999).
- **Habitat selection** – Although adult habitat use has been studied on Vancouver Island (Davis,

unpublished data), work should be done elsewhere, especially in parts of the range where conditions are more extreme. No work has been done on the habitat requirements of metamorphs and juveniles. Experimental and statistical designs for studies of habitat selection are discussed by Manly et al. (1993).

Without a serious commitment to a research and management program of the type outlined here, there is little hope of detecting declines should they occur, reconstructing the factors and events that led to the decline, or taking appropriate management action (Green 1997). Once a population becomes isolated and declines to a small size, it becomes susceptible to extinction resulting from catastrophes, environmental or demographic stochasticity, or genetic factors (Meffe and Carroll 1997). Studying such populations is difficult, expensive, and often indeterminate.

It is not practical to monitor every plant and animal species in British Columbia, but a multi-species approach to monitoring amphibian populations at both a broad geographic level and studying a few populations intensively at a local level, including some experimental approaches, is reasonable and possible (Davis 1999). Amphibians are a good choice for such a program because they are especially sensitive to changes in abiotic conditions, are at a relatively high tropic level, often require more than one habitat during their life cycle, and are relatively easy to monitor with well-developed standard methods (e.g., Heyer et al 1994; Olson et al. 1997; RIC 1999) Also, there is considerable public interest in amphibians and their status (Stebbins and Cohen 1995; Green 1997). The degree to which we undertake such projects will be a reflection of our societal values and a measure of our commitment to stewardship of amphibian species and other elements of biodiversity.

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